Fiber Optic Bragg-Grating Sensors

In-fibre Bragg gratings are sensor elements which are photo-written into optical fibre using intense ultra-violet laser beams and have the potential for the measurement of strain/deformation and temperature with applications reported including monitoring of highways, bridges, aerospace components and in chemical and biological sensors. The development of a fiber Bragg grating (FBG) measuring system plays a significant role in monitoring and recording the actual seismic responses of underground structures, rock mass and bridges etc.

The basic principle of a fiber Bragg grating (FBG)-based sensor system lies in the monitoring of the wavelength shift of the returned Bragg-signal, as a function of the measurand (e.g. strain, temperature and force). The Bragg wavelength is related to the refractive index of the material and the grating pitch. Sensor systems involving such gratings usually work by injecting light from a spectrally broadband source into the fiber, with the result that the grating reflects a narrow spectral component at the Bragg wavelength, or in transmission this component is missing from the observed spectrum. Fig.1 shows this simply and schematiclly.

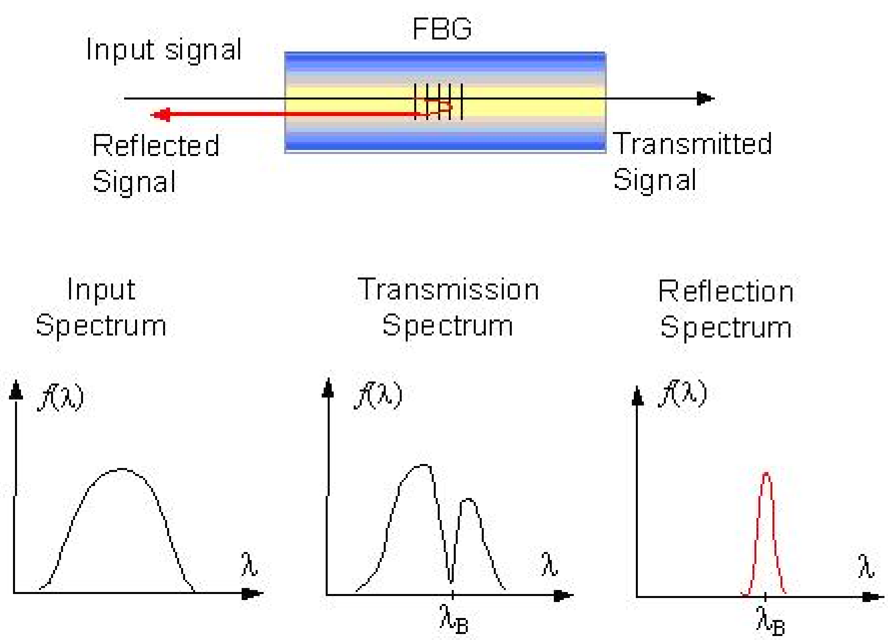


Fig. 1 Funktional principle of a fiber optic Bragg grating

Fig.2 shows an example of a fibre Bragg grating based sensor system for dynamic strain measurement. The sensor-head consists of a glassfibre reinforced polymer (GRP) rockbolt in which the grating is glued by epoxy resin. A 3dBm distributed feedback (DFB) laser, with tunable wavelength in the range from 1548.75 nm to 1551.25 nm, sends an optical signal at an optimised wavelength to the fibre Bragg grating through a fibre optical circulator. A part of the optical signal is reflected from the Bragg grating, goes back through the circulator to a photodetector, and is converted into an electrical signal. The signal is amplified, filtered and then sampled with an oscilloscope. Finally, the sampled signal is processed in a PC system.
The intensity of the reflected optical signal is a function of the Bragg grating wavelength that relates to the applied strain on the fibre Bragg grating. Therefore, the dynamic strain can be derived from the intensity change measurement as function of the wavelength of the reflected optical signal.

This measuring system has a powerful laser source with tuneable and programmable wavelength, so that the system sensitivity can easily be improved by optimizing the laser wavelength. Furthermore, the wavelength sensitivity can be directly determined by using the dc photovoltage measurement and the wavelength change of the laser source without any extra calibration.

The most significant advantages are that:

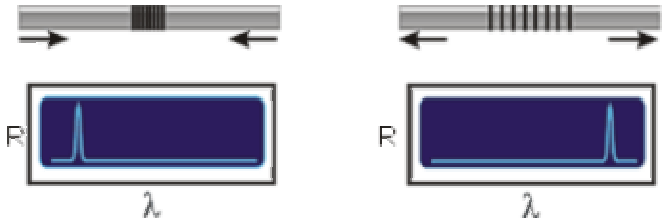
- they are immune to electromagnetic fields;
- they have the ability to take many measurement points along a single fibre - greatly improving the ease at which sensors can be multiplexed; and
- they can be embedded within or bonded to structures without the risk of de-bonding during operation.

Several different optical sensing techniques have found their way into the market place but fibre Bragg gratings (FBGs) are commercially one of the most successful.

However, until recently the large-scale commercial uptake of optical sensing systems has been prevented by the high costs, large system size and high power consumption associated with the opto-electronic read-out unit. Recently, the dramatically falling costsof these units have driven an upsurge in the number of fibre Bragg gratings being used commercially for sensing. The applications areas are very wide - covering wind turbine performance monitoring, oil and gas exploration, bridge and tunnel monitoring, other structural monitoring, marine defence and health.

fiber Bragg Gratings

A fiber (fiber) Bragg Grating (FBG) is a novel optical sensor recorded within the core of a standard optical fiber. It reflects a narrow bandwidth of light which responds faithfully to changes in temperature and strain. Hundreds of FBG sensors can be recorded onto a single optical fiber and interrogated simultaneously with a single instrument - the effect is a very low cost mechanism for distributed monitoring of strain and/or temperature within large structures, particularly suited to design validation and test and to structural health monitoring.



The diagram above illustrates how the strain applied to a Bragg Grating alters the wavelength of reflected light.

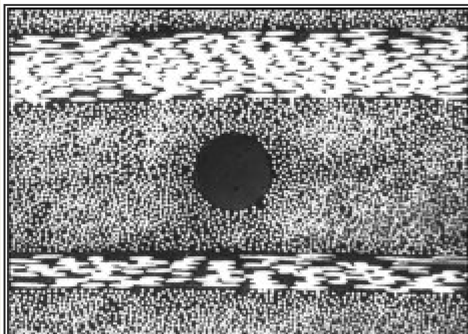
A more detailed description of the workings of fiber Bragg gratings and associated interrogation instrumentation is available via the link below:

An Introduction to fibre Bragg gratings and interrogation techniques
Dr Crispin Doyle, Chief Engineer, Smart Fibres Ltd

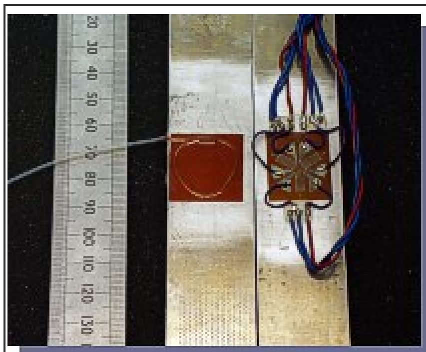
As well as strain and temperature measurement, FBGs can be used for other measurements such as pressure, acceleration and the like by the bare fiber sensor into transducers. These FBG sensors, the technology of Smart Fibres, have numerous significant advantages over more conventional electrical sensor technologies.

Size

The fiber into which FBGs are recorded is tiny, just 0.25 mm or less in diameter. The means that many sensors can be applied to a structure with very little intrusion. Uniquely, a fiber sensor array can be embedded inside a composite to monitor for internal strain, temperature and damage with no affect on the structural performance of the composite.



Magnified cross section of a laminated carbon fiber panel containing an embedded optical fiber sensor (125 µm diameter)



Comparison of electrical strain gauge rosette (right) and the fiber optic equivalent (left)

Multiplexing

Hundreds of FBGs can be written into one optical fiber, and several hundred can be simultaneously interrogated by one multi-channel instrument. This provides a very low-cost mechanism for densely instrumenting even very large structures, compared with technologies where every sensor has a dedicated instrument. Furthermore, optical fiber is already smaller and much lighter than electrical wire and, together with this multiplexing capability, extensive FBG sensor installations can be made that were hitherto impossible in certain applications due to cable mass and volume.

Ease and Cost of Installation

Consider installing a large number of conventional electrical strain gauges. Each gauge needs to be bonded to the structure under test and then the bond pads associated with each gauge need to be bonded. Solder joints then need to be made in-situ between each gauge and its associated bond pads. Then electrical wires need to be soldered in-situ to all of the bond pads and then routed and secured back to the bank of instruments. Finally, the electrical bridge associated with each gauge needs to be balanced before measurements can commence.

By comparison, the structure can be instrumented by hundreds of FBG strain sensors simply by bonding one optical fiber to the structure, connecting it to a single FBG interrogator and pressing a single button to take a strain array reference that is valid for all future readings.

Bearing in mind that the installation engineers are skilled labour, and access to certain structures is difficult and expensive, the cost and time savings available through an optical fiber installation are clearly significant.

Signal Integrity

Optical fiber is a very efficient signal carrier. Because of this, the electrical interrogation unit can be sited many tens on Kms away from the sensing location, whereas conventional electrical strain gauge systems require regular amplification to avoid signal to noise degradation. For monitoring large, remote structures such as sea-bed pipelines or a long rail tunnels, this is a unique and invaluable benefit. Optical sensors are immune from down-lead effects and, since the measurand in a FBG sensing system is wavelength which is unaffected by signal attenuation, it is not possible for the value of a remote sensor to be corrupted whilst being transmitted along a long fiber.

Electrical Immunity

FBG sensors are passive and require no electrical power. Because of this, they are totally immune to interference from electrostatic or radio frequency sources. Furthermore, they are intrinsically safe and can be used to instrument the most hazardous explosive environments

Long-Term Stability

Another significant benefit that FBG sensors offer for remote monitoring is their stability over time. Being a passive sensor, a FBG has zero drift and can be used for many years with no need for recalibration. Indeed, it is practical to attach sensors to bridges for instance and return with an instrument to interrogate the sensors every few years to get a true picture of any structural movement since the last reading. This further increases the economic advantage of the technology since only one interrogation unit can service hundreds of structures

Fatigue Durability

Tests with carbon fiber coupons have shown that embedded fiber sensors show no signs of fatigue or disbonding after one million cycles. Similar tests with glass fiber materials will demonstrate that embedded sensors within wind turbine blades for instance will survive the 25 year service life of the blades themselves. For surface mounted applications, optical fiber sensors are less prone to debonding and are far more resilient to chemicals.

Smart Fibres have been working with FBGs for many years and have developed some novel solutions for applying them to all manner of structures. Details of these Smart FBG sensors are to be found in our Products pages